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Diurnal Changes in Rectal and Body Surface Temperatures of Conscious, Chair-Restrained Rhesus Macaques

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SUMMARY

A system has been established for continuous recording of rectal and body surface temperatures in conscious, chair-restrained rhesus macaques. Diurnal changes in rectal temperature and body surface temperatures of head, back, abdomen, and inner thigh were recorded for 24 hours under conditions of intermittent or constant light. When lights were on for 8 hours (0800 to 1600 hours) and off for 16 hours, maximal rectal temperatures (37.6 ± 0.3 C) were observed at 0900 hours, whereas minimal rectal temperatures (36.7 ± 0.4 C) were demonstrated between 0200 and 0400 hours. Mean rectal temperatures varied 0.9 C during a 24-hour period. A trend of diurnal changes in body surface temperatures was also observed with low surface temperatures recorded between 0400 and 0800 hours. The surface temperatures (33.8 to 36.5 C) were markedly lower than rectal temperatures (36.7 to 37.6 C) under the same experimental conditions. When macaques were subjected to constant light, high rectal temperatures were recorded between 0900 and 1700 hours and low rectal temperatures were observed between 2400 and 0300 hours with a mean variation of 0.7 C (36.3 ± 0.15 to 37.0 ± 0.2). Diurnal body surface temperature changes during constant light were less pronounced than those of rectal temperatures. Furthermore, low surface temperatures of abdomen and inner thigh recorded between 0200 and 0800 hours were similar to those obtained with macaques exposed to the light-dark conditon.

In a review of the literature, few studies reported normal values of rectal and body surface temperatures in rhesus macaques. Comprehensive information on diurnal rectal and body surface temperature changes in the nonhuman primate was also lacking. Erikson[1] reported diurnal vaginal temperatures for 12 hours in 9 unrestrained rhesus macaques kept in a room with constant light for 8 hours and darkness for 16 hours. Vaginal temperatures were measured twice with a clinical thermometer during the period between 1000 and 2200 hours; the interval between temperature measurements was 3.5 to 5.0 hours. The highest temperature was recorded in early afternoon and the lowest at 2200 hours. The diurnal temperature variation ranged from 0.72 to 1.66 C. Diurnal changes in colonic temperature of restrained squirrel monkeys were determined with a thermistor.[2] Squirrel monkeys displayed a prominent circadian rhythm in colonic temperature, when exposed each 24 hours to an equal distribution of light-dark cycles. Colonic temperature was also maintained during 6 hours of mild cold exposure (20 C) at all circadian phases. However, in constant light, the squirrel monkey's ability to regulate colonic temperature against similar cold exposure was impaired.

In a classic work, Galbraith and Simpson[3] measured the axillary temperature with clinical thermometers for recording diurnal changes in monkeys (species unspecified). When monkeys were kept continuously in the light, there was no regular diurnal wave. The regular diurnal wave was observed only when monkeys were kept in 12 hours of darkness and 12 hours of constant light. The effect of light on diurnal changes in deep body temperature was also demonstrated in caged capuchin monkeys (*Cebus* sp).[4] In a study with rhesus macaques, a rhythm of subcutaneous temperature changes was measured by thermistor surgically implanted under the dorsal skin of the neck.[5] The rhythm was

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influenced by both the lighting and the feeding schedules. Furthermore, Rohles et al[6] measured the mean body surface temperature at the groin and calf of a chimpanzee, but no detailed procedures were given. Maximal surface temperatures were recorded between 1600 and 2400 hours, indicating a possible diurnal surface temperature variation.

Since the rhesus macaque is commonly used as a primate model for the study of human fever,[7] toxemia,[8,9] and infectious diseases,[10-12] simple techniques for measuring rectal and body surface temperatures are essential for performing these experiments. The purposes of the present study were (1) to develop a noninvasive system for obtaining long-term (> 48 hours) continuous recordings of rectal and body surface temperatures of restrained macaques and (2) to establish baseline diurnal rectal and body surface temperature values of conscious, chair-restrained macaques.

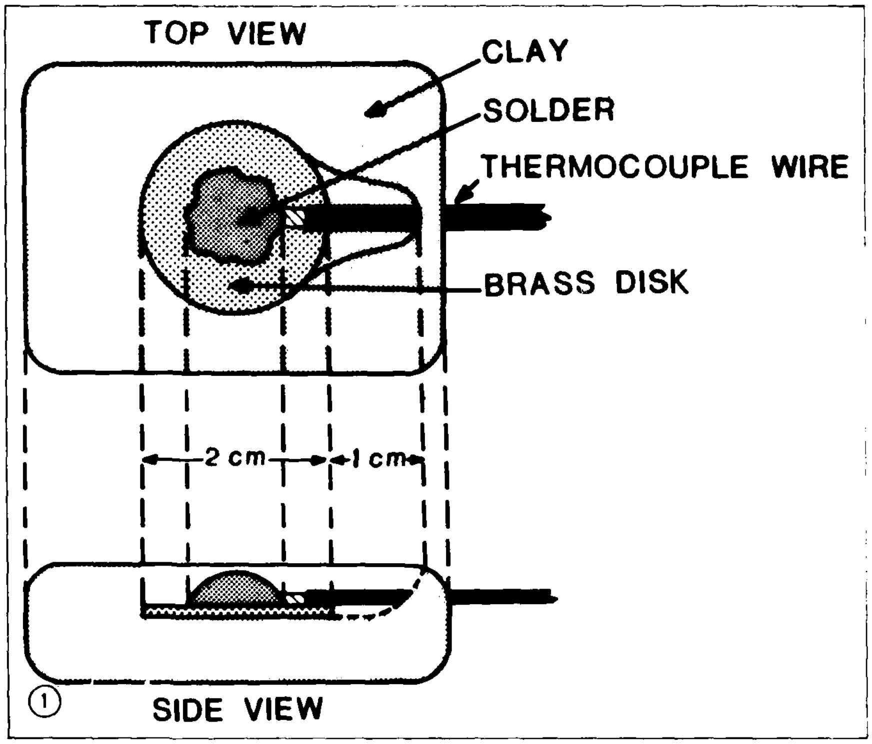

Fig 1—Preparation of the body surface electrode.

Materials and Methods

Experimental Design—Eleven apparently healthy rhesus macaques weighing 4.2 to 10.1 kg were allocated into 2 groups. Group I (n = 5) was subjected to 8 hours' light (0800 to 1600 hours), followed by 16 hours' darkness in a 24-hour period. Group II (n = 6) was exposed to constant light. All macaques were chair-restrained in an isolation room,[a] with constant temperature (23 ± 1 C) and relative humidity (20 ± 1%) and fed with monkey chow[a] at 0900 and 1600 hours. Water was provided ad libitum. Temperature recordings were started approximately 24 hours after chair-restrained procedure.

Preparation of Thermocouple Electrodes—Fabrication of thermocouple electrodes for continuous measurements of body surface temperatures consisted of stripping 1 cm of insulation from the ends of a 3.0 to 3.6 m length of thermocouple wire.[b] The exposed strands were twisted together and soldered to a 2-cm diameter brass disk 0.13 mm thick. The soldered junction was strengthened by embedding the disk and an adjacent 5 to 10 mm of wire in plastic cement.[c] This was done by forming a mold around the disk and wire with modeling clay. Plastic powder and liquid were mixed and poured into the mold to form a 2 to 3 mm layer over the brass disk (Fig 1). After hardening, the disk was removed from the mold and the rough edges of the plastic were filed smooth. Four or more holes were drilled around the periphery of the disk to facilitate suturing. The other end of the wire was attached to the terminals of a plug assembly[d] which linked the electrode to a potentiometer.[e] The potentiometer was calibrated with the electrode immersed in a constant temperature waterbath.[f]

Measurements of Rectal and Body Surface Temperature—Approximately 24 hours before temperature recordings, the macaques were sedated with ketamine (10 mg/kg). Four thermocouple electrodes were sutured to the occipital region of the head, lower abdomen, back (thoracic region), and inner thigh, respectively. Skin temperatures from the 4 different sites of the conscious, chair-restrained macaques were recorded continuously on a potentiometer.[e] The rectal temperature was measured with a stainless steel rectal probe,[g] lubricated with sterile jelly, and inserted 3 to 4 cm into the rectum. The rectal probe, secured to the tail with adhesive tape, was connected to a telethermometer.[h] The output signals were fed into a minicomputer[i] via a universal (DC) preamplifier of a recorder[j] (Fig 2). A computer program (Fig 3) for printing out rectal temperatures from signals of the recorder was incorporated into the recording system. The calibration procedures were identical, as described for thermocouple electrodes. All temperatures were recorded continuously for 48 hours. Data from a complete 24-hour cycle (2400 to 2400 hours) were analyzed to obtain mean values and SEM.

Results

Rectal Temperature—Diurnal changes in rectal temperature were observed in the conscious, chair-restrained rhesus macaques exposed to constant light for 24 hours or with 8 hours' light exposure (0800 to 1600 hours) (Fig 4). With lights on for 8 hours and off for 16 hours (complete darkness), maximal rectal temperatures (37.6 ± 0.3 C) were recorded at 0900 hours and decreased thereafter. Minimal rectal temperatures (36.7 ± 0.4 C) were demonstrated between 0200 to 0400 hours. Mean rectal tem-

[a] Ralston Purina Co, St Louis, Mo.

[b] 28 AWG, 2-conductor, Revere Corp, Wallingford, Conn.

[c] Cranioplastic Cement, Plastic Products Co, Roanoke, Va.

[d] Model 7313, Honeywell Industrial Division, Fort Washington, Pa.

[e] Electronik 111/112, Honeywell Industrial Division, Fort Washington, Pa.

[f] Polyscience waterbath (Model J4-9621), American Instrument Co, Silver Springs, Md.

[g] Rectal probes (Model 403), Yellow Springs Instrument Co, Yellow Springs, Ohio.

[h] Telethermometer (Model 44TA), Yellow Springs Instrument Co, Yellow Springs, Ohio.

[i] Minicomputer—Digital pdp 11/34, Digital Equipment Corp, Maynard, Mass.

[j] Recorder—Model Mark 200, Brush Instruments Division, Cleveland, Ohio.

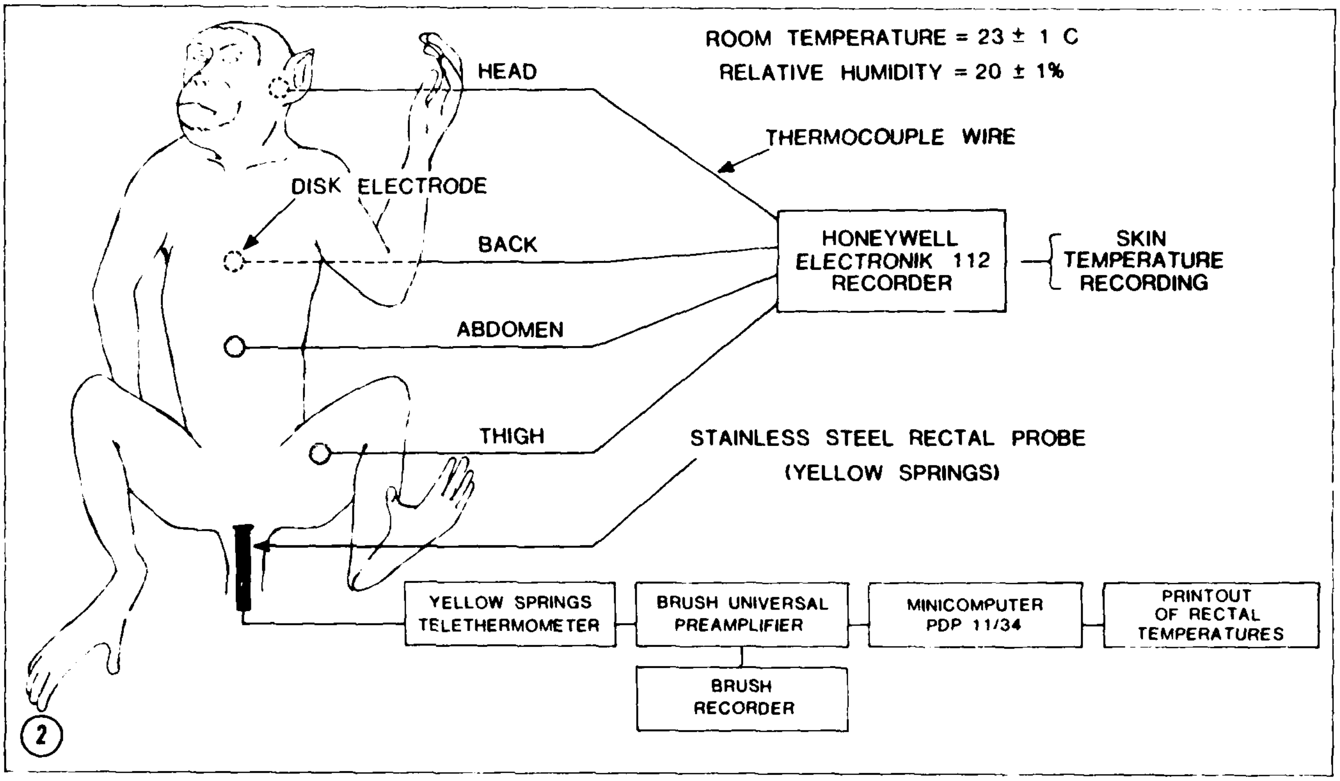

Fig 2—Schema for recording rectal and body surface temperatures in conscious chair-restrained rhesus macaques.

peratures varied 0.9 C during a 24-hour period. When macaques were subjected to constant light, high rectal temperatures were recorded between 0900 and 1700 hours and decreased thereafter. Low rectal temperatures were observed between 2400 and 0300 hours. The diurnal rectal temperatures varied from 36.3 ± 0.15 C to 37.0 ± 0.2 C; a change of 0.7 C.

Body Surface Temperature—Under conditions of 8 hours' light and 16 hours' darkness, a trend of diurnal changes in surface temperatures was observed on the head, back, abdomen, and inner thigh (Fig 5). In general, low surface temperatures were recorded between 0400 and 0800 hours, and high surface temperatures, between 1000 to 1500 hours. The surface temperatures (33.8 to 36.4 C) were markedly lower than rectal temperatures (36.7 to 37.6 C) under the same experimental conditions. With lights on at all times, diurnal surface temperature changes became difficult to identify except at the sites of the abdomen and the inner thigh. Low surface temperatures were recorded between 0200 and 0800 hours.

Table 1 summarizes the results of maximal and minimal temperature changes of rectal and individual surface temperature changes of rhesus macaques within 24 hours. The time or duration for recording maximal and minimal temperatures are also indicated. Constant light impaired diurnal changes of rectal and surface temperatures in general, especially for the surface of the head and back.

Discussion

Diurnal temperature change is a normal phenomenon of biological variation during a nearly 24-hour period. Physiologic and biochemical aspects of circadian rhythm and neural mechanisms for the regulation of these periodic changes have been reviewed by Menaker,[13] Aschoff and Weber,[14] and Rusak and Zucker.[15] Effects of food and light on modification of circadian rhythm were reported by Iampietro et al[16] and Fuller et al.[2]

Elizondo[17] indicated that the "normal" core body temperature of many mammalian species ranged from 36 to 39 C. The reported values of "body" temperature of normal rhesus macaques[18,19] fall within these limits. "Body" temperatures in primates have been determined from different sites including back muscle (longissimus dorsi),[18,19] vagina,[1] axilla,[3] and esophagus[20] (under anesthesia). Baseline rectal temperatures obtained from the present study ranged from 36 to 37 C under constant light. These rectal temperature values are similar to human body temperature (37 C), but lower than those of reported values obtained from back muscles for rhesus macaques.[18,19] The difference in normal body temperature of the same primate species may be due to different techniques used. For example, when body temperature is measured from the back muscle with thermocouple wires as demonstrated by others,[18,19] the traumatized or injured muscle may produce local vasodilation[21] and increase the temperature. Furthermore, emotional stress resulting from human handling of the conscious macaque by inserting a probe or clinical thermometer into the rectum may also increase the rectal temperature. However, in the present study, we attempted to eliminate these disturbing factors, so that more

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FIF TI: TEMP2.FTN
        DIMENSION TEMP(4),DT(3),TIM(2),ATEMP(29)
        INTEGER BUF(4,2),IBUF(40),IBUFNO,ADNUM(30)
        IBFCNT=0            !IBFCNT WILL TELL NUMBER OF PASSES THROUGH
        TYPE *,' IS SAMPLE TIME TO BE MEASURED IN SECONDS OR MINUTES S,M'
        ACCEPT 45,ALPHA
 45     FORMAT(A1)
        IF(ALPHA.EQ.'M')GO TO 55
        TYPE *,' ENTER CHANNEL # AND SECONDS BETWEEN SAMPLES'
        ACCEPT 40,ICHAN,ITIME
 40     FORMAT( 2I5)
        IPRSET=-100*ITIME
        CALL CLOCKA(5,IPRSET)            !CLOCK RATE SET AT 100 HZ
        GO TO 35
55      TYPE *,' ENTER CHANNEL # AND MINUTES BETWEEN SAMPLES'
        ACCEPT 41,ICHAN,ITIME
41      FORMAT( 2I5)
        CALL CLOCKB(5,-100,2,IND)
        IF(IND.EQ.1) GO TO 44
        TYPE *,' ERROR IN LOADING CLOCKB'
44      CONTINUE
        IPRSET=-60*ITIME
        CALL CLOCKA(0,IPRSET)
 35     TYPE *,' ENTER NUMBER OF SAMPLES TO BE TAKEN'
        TYPE *,'# OF SAMPLES MUST BE A MULTIPLE OF 4 OR IT WILL BE TRUNCATED'
        ACCEPT 50,ISAMPL  !FOR PRESENT MULTIPLE OF 4
50      FORMAT(I5)
        CALL CLREF(30)
        CALL SETIBF(IBUF,,,BUF(1,1),BUF(1,2))
        CALL RLSBUF(IBUF,,0,1)
        CALL ADSWP(IBUF,4,0,64,1,30,0,ICHAN,1)
75      CALL DATE(DT)
        CALL TIME(TIM)
        TYPE 12
12      FORMAT(1H,/,'  DATE',9X,'TIME')
        TYPE 10,DT,TIM
10      FORMAT(1H,3A4,4X,2A4)
        IBUFNO=IWTBUF(IBUF,30) + 1
        IF(IBUFNO.LT.1) GO TO 99  !STOP PROGRAM
        TYPE 15
15      FORMAT(1H,29X,'TEMPERATURE')
C  *************  DECISION ROUTINE TO DETERMINE TEMPERATURE VALUES  ************
        DO 300 I=1,4
        IF(BUF(I,IBUFNO).LE.ADNUM(1)) GO TO 250
        DO 200 J=1,29
        K=J+1
        IF(BUF(I,IBUFNO).GT.ADNUM(J).AND.BUF(I,IBUFNO).LE.ADNUM(K)) GO TO 220
200     CONTINUE
C       OVERFLOW
        TEMP(I)=99.
        GO TO 500
220     TEMP(I)=ATEMP(J)
        GO TO 500
C       UNDERFLOW
250     TEMP(I)=0.
C *************************************************************
500   WRITE(5,100)BUF(I,IBUFNO),TEMP(I)
100     FORMAT(1H,13X,I8,5X,F10.2)
300     CONTINUE
        NBUF=IBUFNO-1
        CALL RLSBUF(IBUF,,NBUF)
        IBFCNT=IBFCNT+1
        IF(IBFCNT.EQ.ISAMPL/4) GO TO 99 !STOP
        GO TO 75
99      CALL STPSWP(IBUF,0)
       DATA ADNUM/2161,2197,2220,2240,2255,2276,2301,2322,2338,
     1,2362,2393,2416,2433,2453,2478,2499,2416,2536,2558,2580,2601,
     2,2623,2645,2665,2683,2705,2733,2758,2781,2804/
        DATA ATEMP/35.,35.25,35.5,35.75,36.,36.25,36.5,36.75,37.,
     137.25,37.5,37.75,38.,38.25,38.5,38.75,39.,39.25,39.5,
     239.75,40.,40.25,40.5,40.75,41.,41.25,41.5,41.75,42./
        STOP
        END
```

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Fig 3—Computer program for recording rectal temperatures.

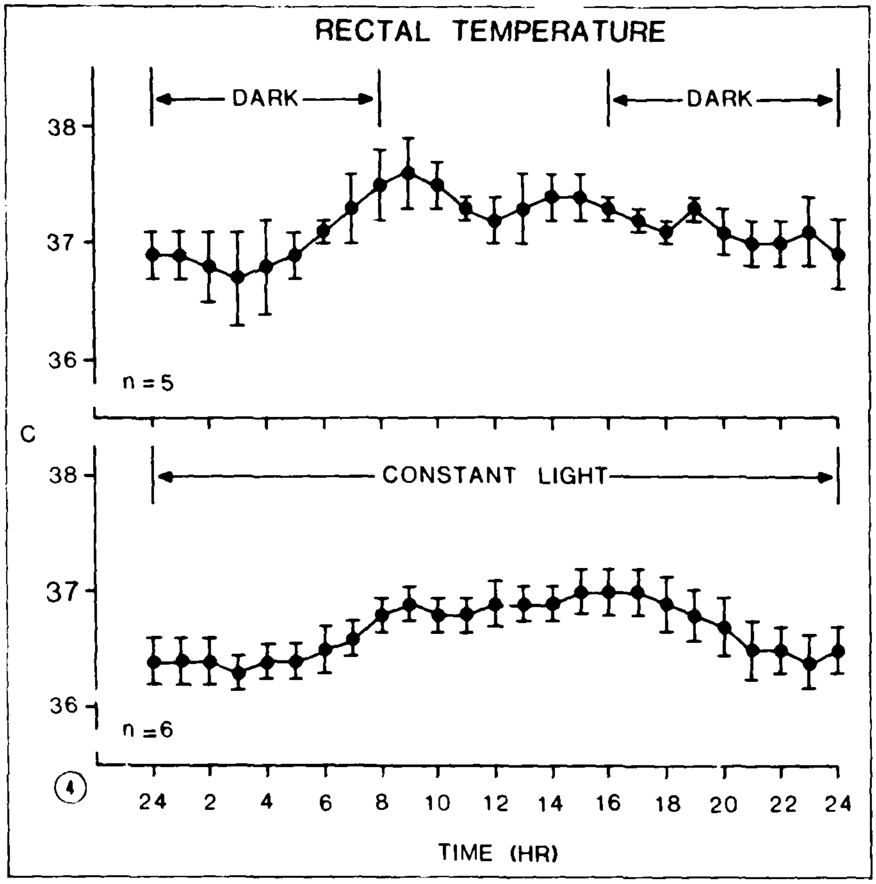

Fig 4—Diurnal changes in rectal temperatures of conscious, chair-restrained rhesus macaques.

TABLE 1—Summary of Results

Location	Diurnal rectal and body surface temperature changes: Maximal temperature	Minimal temperature	Maximal temperature change during 24 hours	Time of maximal and minimal temperature changes (hours of day): Maximum	Minimum
8 HOURS' LIGHT + 16 HOURS' DARKNESS ($n = 5$)					
Rectal	37.6 ± 0.3	36.7 ± 0.4	0.9	0900	0200–0400
Body surface					
Head	36.2 ± 0.6	35.1 ± 0.3	1.1		
Abdomen	34.9 ± 1.0	33.8 ± 0.8	1.1	1000–1500	0400–0800
Back	35.8 ± 0.7	34.3 ± 0.6	1.5		
Inner thigh	36.4 ± 0.3	35.1 ± 0.5	1.3		
24 HOURS' CONSTANT LIGHT ($n = 6$)					
Rectal	37.0 ± 0.2	36.3 ± 0.2	0.7	0900–1700	2400–0300
Body surface					
Head	35.3 ± 0.8	34.5 ± 0.8	0.8		
Abdomen	36.8 ± 0.7	34.8 ± 0.8	1.0	Not clearly evident	0200–0800*
Back	35.9 ± 0.7	34.8 ± 0.8	1.1		
Inner thigh	36.3 ± 0.8	35.0 ± 0.9	1.3		

* Only for abdominal and inner thigh surface temperatures.

closely realistic values of rectal temperatures were obtained. Diurnal changes of rectal and body surface temperatures in conscious chair-restrained rhesus macaques varied approximately 1 C during a 24-hour period. Surface temperatures were lower than the rectal temperature but the timing for reaching maximal and minimal values was different between surface and rectal temperatures. Since surface temperature changes might be associated with cutaneous vasoconstriction and vasodilation for body temperature regulation under various environmental light conditions, this may explain why diurnal skin changes were less pronounced than changes of rectal temperatures.

Baker et al[22] demonstrated variability of body surface temperatures at different sites of conscious pigtail macaques (*Macaca nemestrina*). Different base-line values for tail, foot, and mean surface temperatures were also observed in the squirrel monkey (*Saimiri sciureus*) by Adair and Adams.[23] Although surface temperatures of the inner thigh[24,25] and ear of rhesus macaques have been reported, base-line thigh surface temperatures (37.2 to 37.9 C) are markedly higher than those values obtained from the same site in the present study (36.4 ± 0.3 C at 0900 hours). This discrepancy might be due to different techniques in measuring surface temperature and different experimental conditions. Higher thigh surface temperatures recorded by other investigators might be the result of surgical operation, in which a durable thermode implant was placed in the hypothalamus.[25] Furthermore, the complicated experimental design and restraint of the macaque may also provide additional stress to alter surface temperature.

The selection of a rigid stainless steel rectal probe was based on the evidence that chair-restrained macaques were not able to push the probe out of the anus as easily as a flexible, soft probe. However, the main disadvantage for using the rigid rectal probe was the possibility of damaging the rectum when the macaque was too active or could not be easily adapted to chairing. Under this circumstance, the use of a soft rectal probe is recommended, providing that the segment of the probe wire outside of the anus is supported by a rigid rod and fixed firmly to the macaque's tail with adhesive tape. The temperature recording system described here not only provides less stress on the animal, but also operates simply and automatically for data processing. Because rhesus macaques reveal certain diurnal changes of rectal and body surface temperatures, the timing for daily measurements of temperatures should be consistent to avoid errors. Under normal circumstances, the diurnal temperature variation of a rhesus macaque may be approximately 1 C.

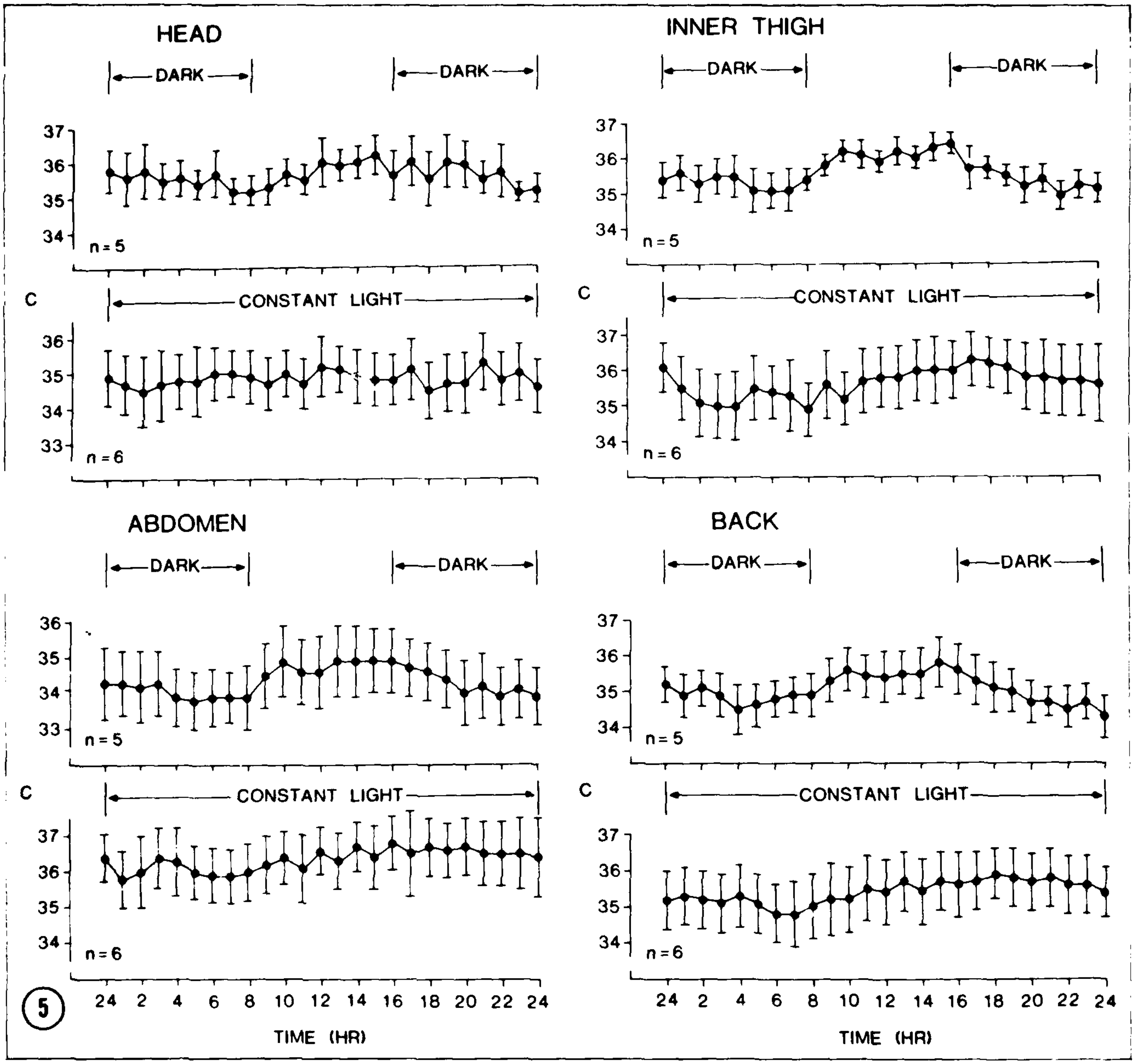

Fig 5—Diurnal changes in body surface (head, inner thigh, abdomen, and back) temperatures of conscious chair-restrained rhesus macaques.

However, when fever is induced, diurnal temperature changes are difficult to predict. Thus, a daily continuous recording of rectal and body surface temperatures appears to be the best approach for correct and accurate interpretations of data.

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